REPORT No. 625

A DISCUSSION OF CERTAIN PROBLEMS CONNECTED WITH THE DESIGN OF HULLS OF FLYING BOATS AND THE USE OF GENERAL TEST DATA

By Walter S. Diehl

SUMMARY

A survey of the problems encountered in applying general test data to the design of flying-boat hulls. It is shown how basic design features may be readily determined from special plots of test data. A study of the effect of the size of a flying boat on the probable limits to be covered by the general test data is included and recommendations for special tests and new methods of presenting test data for direct use in design are given.

INTRODUCTION

The National Advisory Committee for Aeronautics has published a number of Technical Reports, Technical Notes, and Technical Memorandums (references 1 to 23, inclusive) giving data obtained from general tests on flying-boat hulls. A full description of the general method of testing a flying-boat hull may be found in references 3 and 23.

The term "general test" implies that the full range of useful loadings, trim angles, and speeds are investigated rather than one particular or specific condition corresponding to a normal unloading during a take-off. The general test requires determination, for a series of constant loads and at each of a series of fixed trim angles, of the curves of resistance and moment against speed. These data may be cross-plotted to obtain the best trim for each load and speed. The final data are usually given in coefficient form for the best trim condition.

Model test data on hull lines are used primarily and, in order of importance, for (1) comparison of relative advantages and disadvantages of various lines, (2) determination of best beam for a given load and get-away speed, and (3) calculation of take-off resistance. Extended use of the available general test data has brought out a number of modifications that appear desirable from the viewpoint of the designer. These modifications are concerned less with methods of testing than with presentation and possible interpretations of the data. It is believed that a general discussion of the problems of interpreting hull data may serve a useful purpose in clarifying some of the points involved.

SELECTION OF BEST BEAM

In reference 3, Shoemaker and Parkinson give a method of selecting the best beam from the data obtained in a complete tank test, as follows:

"The first step in determining the water resistance is the selection of the proper beam. A number of formulas are in common use for determining the beam but, since the best compromise depends upon the characteristics of the hull used, they are only rough guides. The curves of figure 1 [same as fig. 10, reference 3] offer a somewhat better means for making a first approximation, which can be corrected after the final resistance curve is constructed. The smallest beam which does not make the hump resistance seriously high should be chosen, because a small beam is favorable to low resistance in the high-speed range. Considerations of structural weight also favor a small beam. It should be noted, however, that excessive reduction in beam may cause objectionable spray characteristics.

"The hump of the total resistance curve will occur at approximately the same speed coefficient as the hump of the best-angle curves * * *. For model No. 11 the value of C_V at the hump is about 2.3. Referring to figure 1, the value of Δ/R for this speed is 4.5 at

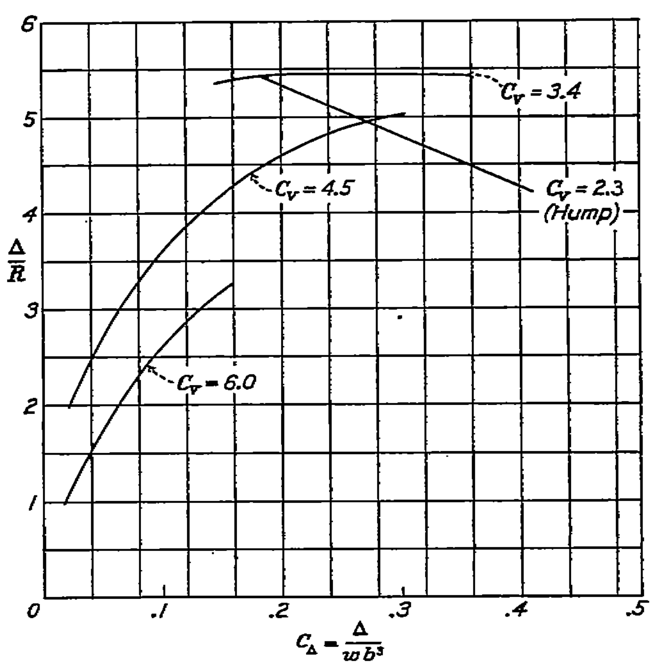

FIGURE 1.—Variation of Δ/R with C_Δ for model 11 (same as fig. 10 of reference 3).

$C_\Delta=0.35$. This value of Δ/R is about the lowest that will give satisfactory performance at the hump; hence the beam should not be decreased beyond this point,

at least for the first trial. It may be assumed that the load Δ at the hump is roughly nine-tenths of the gross load."

This method has the desirable advantages of being direct and easy to use. Experience shows, however, that the indiscriminate use of data based on the best angle of trim may lead to erroneous conclusions. Unfortunately, the tests in reference 3 do not cover enough range in trim angles and loadings to illustrate the marked difference between free-to-trim and best-trim data. Later tests in reference 10 cover a greater range and may be used for the purpose of illustrating the point involved. Figure 2 gives the Δ/R at hump speed for best trim as taken from figure 11 of reference 10 and for free-to-trim condition as calculated from the test data. If a value of $\Delta/R \geq 5.0$ is required, the best trim-angle data indicates $C_\Delta=0.42$ whereas the free-to-trim data indicates $C_\Delta=0.22$. These values represent a difference of about 25 percent in the beam required. There is ample evidence to show that the free-to-trim hump resistance may be 20 to 30 percent greater than the resistance at best trim. There is also sufficient evidence to show that in most cases the actual operating conditions approximate very closely the free-to-trim condition at the hump. It seems highly desirable to base the actual design calculations on the free-to-trim condition only. A discussion of the free-to-trim data will be given later.

There is reason to believe that the superior planing action of a narrow beam hull has been overemphasized. The test data on hull lines show that although it is sometimes possible to obtain improved lines, enabling the use of heavier load coefficients, there is normally very little gain in planing action with a narrow beam in a geometrically similar series. The general effect of variation in beam may be clearly shown on a plot of Δ/R contours with C_Δ as ordinates and C_V^2 as abscissas. Constant angle unloading is shown on this plot by a straight line drawn from the initial load coefficient C_{Δ_0} to the get-away value of C_V^2. An example of this type of plotting is given on figure 3 taken from an unpublished N. A. C. A. test. The solid diagonal line sloping downward from left to right represents a constant angle take-off with $C_{\Delta_0}=0.62$ and $C_{V_G}{}^2=38.0$. The value of C_{Δ_0} varies inversely as the cube of the beam and the value of $C_{V_G}{}^2$ varies inversely as the beam. The effect of a 10-percent change in beam is shown by the two broken lines, the upper line being for the smaller beam. Points representing 80 percent V_G are indicated by circles. The approximate values of Δ/R at the hump and at 80 percent V_G are:

Beam ratio b/b_0	0.90	1.00	1.10
Δ/R at hump	4.48	4.72	4.95
Δ/R at $0.80V_G$	4.70	4.55	4.45

A 10-percent reduction in beam therefore gives about 3 percent reduction in resistance at 0.80 V_G but this reduction appears to be more than offset by about 5 percent increase in hump resistance.

Data plotted in figure 3 are based on best trim. This figure would be more useful in the determination of best beam if free-to-trim data were used for values of C_V^2 less than about 10. An abridged form may be employed for this purpose. A curve drawn through the lowest points on each contour in the upper left-hand side of figure 3 locates the values of C_Δ, C_V^2, and Δ/R at the hump. This curve can be drawn alone on a separate chart as on figure 4, which is simply an approximation based on the free-to-trim curve of figure 2. The

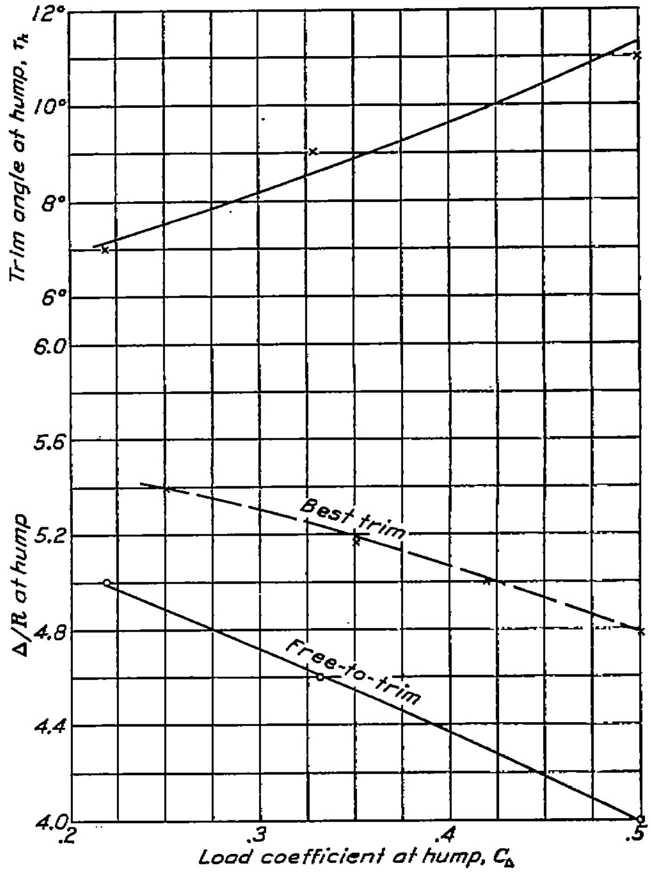

FIGURE 2.—Variation of Δ/R and maximum trim angle at hump for model 110 (based on data from reference 10).

value of C_v at the hump would normally increase slightly as the load coefficient is increased so that the graduated line on figure 4 should incline very slightly to the right. The main value of figure 3 is to emphasize the importance of hump resistance in determining the beam. If a minimum value of Δ/R is specified or required at the hump there is not very much allowable range in beam. The value of C_V^2 at the get-away normally lies between 30 and 50 but extreme values of 20 and 100 may be assumed to illustrate the restricted variation in beam. Light broken lines are drawn on figure 4 to pass through the $\Delta/R=4.5$ point and intersect the C_V^2 axis at 20 and at 100. These two lines intersect the C_Δ axis at 0.47 and 0.37. Since C_Δ varies inversely as the cube of the beam

$$\frac{b_1}{b_2}=\sqrt[3]{\frac{0.47}{0.37}}=1.08$$

or the total variation in beam will be less than 10 percent. A plotting in the form shown on figure 2 will ordinarily be sufficiently accurate. Its value can be increased slightly by inclusion of the curve of C_V against C_Δ so that the initial value of C_Δ may be obtained. When C_V is known for hump speed, it is unnecessary to assume

$$C_{\Delta_h}=0.9\ C_{\Delta_0}$$

Since

$$C_{\Delta_h}=C_{\Delta_0}\left[1-\left(\frac{C_{V_h}}{C_{V_G}}\right)^2\right]$$

or

$$C_{\Delta_0}=\frac{C_{\Delta_h}}{\left[1-\left(\frac{C_{V_h}}{C_{V_G}}\right)^2\right]} \qquad (1)$$

the subscript h denoting hump values.

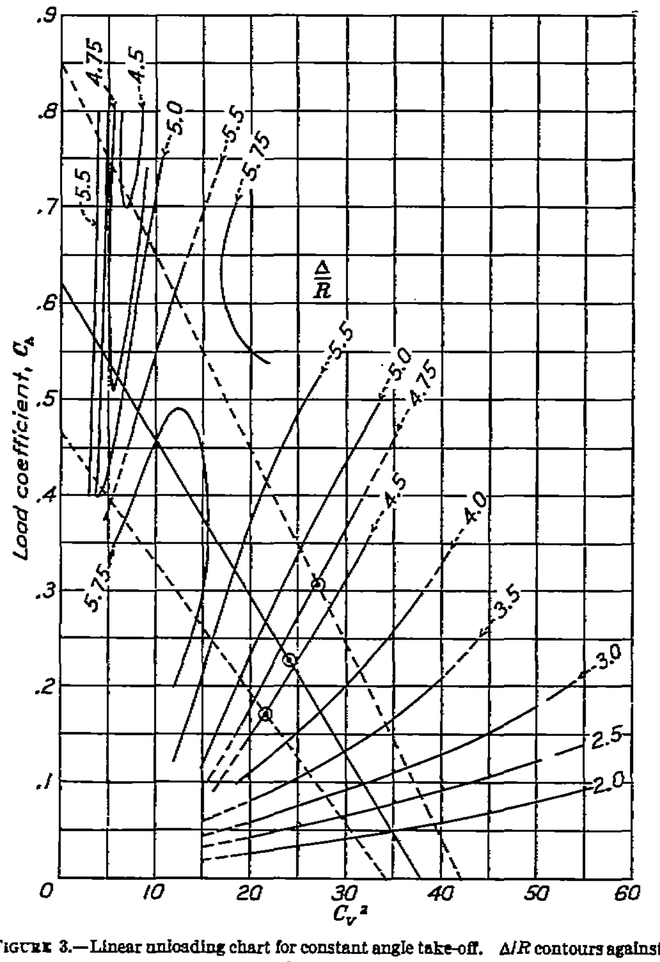

FIGURE 3.—Linear unloading chart for constant angle take-off. Δ/R contours against C_Δ and $C_V{}^2$.

It is important to note that in these approximations C_{V_G} must be based on the get-away speed corresponding to the wing angle of attack at hump speed. The hull angle τ_{max} is given in figure 2 and from it the wing angle may be obtained. The get-away speed is usually assumed to be about 5 percent greater than the stalling speed.

MAXIMUM ANGLE OF TRIM

In free-to-trim tests the maximum angle of trim assumed in passing through the hump increases as the initial load is increased. This characteristic serves to limit the load that can be carried on a given beam since large angles of trim mean high resistance, objectionable spray, etc. The maximum desirable trim angle at the hump decreases slightly as the size of the hull is increased. For a small flying boat it is probably of the order of 12°; for a very large flying boat it probably should be of the order of 10°, or even 8° if practicable.

The maximum angle free-to-trim can be obtained by cross-plotting the usual general test data, but it would be highly desirable for the designer to have this angle given as a part of the general test data. A very satisfactory form appears to be a plot of τ_h against C_Δ as shown in figure 2.

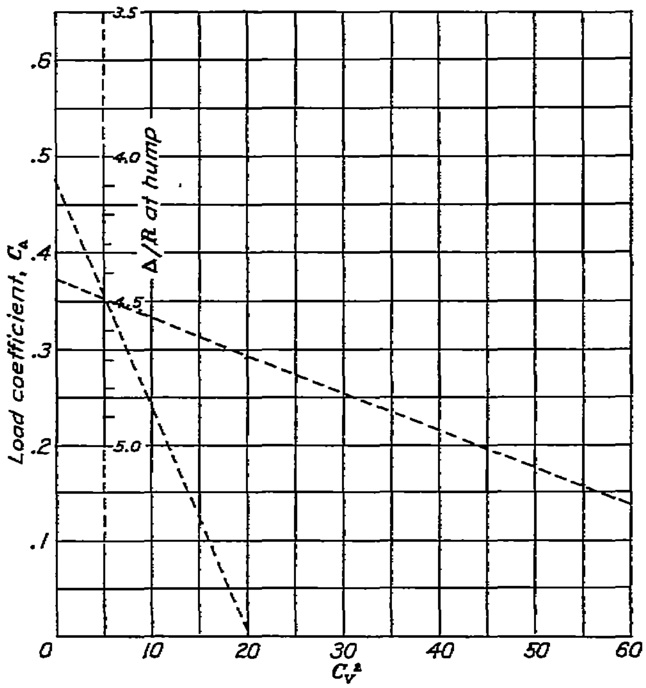

FIGURE 4.—Simplified chart for selection of minimum beam. Δ/R at hump speed against C_Δ and $C_V{}^2$.

The maximum trim at the hump can be controlled only within narrow limits. Moving the center of gravity forward may result in porpoising at planing speeds. This condition will be discussed later. Some diving moment is obtained from the thrust moment and from full-down elevators. An analysis of a number of wind-tunnel model tests shows that the maximum elevator moment corresponds to a lift coefficient of $C_{L_T}=1.00$ for horizontal tail surface or

$$M=q_eS_tl \qquad (2)$$

where q_e is the effective dynamic pressure over the tail surfaces. As a first approximation the slipstream ve-

139778—39——18

locity may be assumed at 100 miles per hour. For preliminary design purposes it is desirable to have the available moments in terms of the initial displacement. These values can be obtained by using

$$M=K\Delta_0^{4/3} \tag{3}$$

The variation in K is less than might be expected, extreme values being approximately $K=0.040$ and $K=0.080$ with most of the designs grouped around 0.060.

The effect of elevator moment could be simulated by including curves with diving moments $M=-0.060\Delta_0^{4/3}$ and $M=-0.120\Delta_0^{4/3}$. These values are intended to apply only in the region of the hump but, where slipstream velocity is a determining factor, they will also apply at planing speeds.

MOMENTS—VECTOR DIAGRAMS

It has been customary to give moments in coefficient form defined by

$$C_M=\frac{M}{wb^4} \tag{4}$$

This form is consistent with the load and resistance coefficients, $C_\Delta=\frac{\Delta}{wb^3}$ and $C_R=\frac{R}{wb^3}$. It is of interest to note the relation

$$M=\Delta\left(\frac{C_M}{C_\Delta}b\right) \tag{5}$$

where $\left(\frac{C_M}{C_\Delta}b\right)$ is the arm upon which the displacement Δ must act to produce the moment M. A coefficient in this form has considerable merit and may eventually be found the best available. However, a moment coefficient defined by

$$C_M=\frac{M}{\Delta^{4/3}} \tag{6}$$

has obvious advantages in preliminary studies where the beam is unknown. This form has shown considerable promise in analyses of data from the Washington Navy Yard towing basin.

Moments about the reference *c. g.* may be converted to any desired actual *c. g.* by either analytical or graphical methods similar to those used in converting wind-tunnel test data. The graphical method is usually employed. In this method the resultant force $F=\sqrt{\Delta^2+R^2}$ is divided into the moment M to obtain the moment arm a. A circle of radius a is then drawn with the reference *c. g.* as its center. The lift acts normal to the water surface and the drag acts parallel to the water surface. The resultant vector will be tangent to the moment circle and incline aft from the vertical by the angle

$$\Phi=\tan^{-1}(R/\Delta) \tag{7}$$

If the calculations are made in coefficient form the radius of the moment circle will be in terms of the beam.

The vector diagram is very helpful when properly used. All presentations of test data should contain at least one diagram of the resultant force vectors for the benefit of those who are familiar with its use. Several types may be considered. One type would be the vectors at a series of values of C_v for a best trim-angle take-off starting with an intial displacement giving a standard minimum Δ/R at the hump, as previously outlined in the discussion of free-to-trim data. A plot of the vectors at hump speeds for a series of load coefficients would also be of value. It is unnecessary to give a great number of vectors spaced at brief intervals—the diagram is probably clearer and more useful when a limited number of selected vectors are shown.

LOCATION OF CENTER OF GRAVITY

The location of the center of gravity with respect to the step must be selected to give the best compromise at rest, at hump speed, and at high speed. The basic condition may be taken as the initial trim τ_0. Operation reports covering values of τ_0 from about 0° to 5° indicate that best results are probably obtained with the main planing bottom between 1° and 2° to the horizontal for flying-boat hulls and between 2° and 3° for seaplane floats. The second condition in importance is to avoid high moments and inefficient trim at planing speeds. The third condition is to avoid excessive trim by the stern at hump speed. Unstable longitudinal oscillations, or porpoising, are highly undesirable at any speed. In general, these conditions are most likely to be met, but not necessarily so, when the initial trim is within the limits given. Some compromise will often be necessary in order to obtain zero or low moments in the high-speed planing condition.

Moving the center of gravity forward to reduce excessive trim at the hump is equivalent to reducing trim at rest and at planing speed also. An appreciable improvement can sometimes be obtained, but porpoising may be expected if the initial trim is too low. Satisfactory designs employing hulls of the type represented by the N. A. C. A. model 11 (reference 3) may be expected to give optimum performance with the center of gravity so located that a plane passed through the center of gravity and the step edge at a point midway between the keel and chines makes an angle of about 20° with the transverse plane defined by the step. Extreme limits of satisfactory operation have been between 15° and 25° for this dihedral angle for hulls of the "Model 11" type. The actual angle giving best results is apparently some function of the relative length of the forebody and afterbody measured on the static water line. The published N. A. C. A. data have not included representative water lines at rest, so that accurate tabulation on this basis is impracticable. On the basis of over-all lengths, the center of gravity locations used in the tests are:

Model	Reference	Ratio forebody (total length)	Center of gravity angle (deg.)
11	3	0.63	18
11	10	.63	32
26	9	.61	18
44	17	.62	29
40 Ac	2	.56	15
47	21	.51	7
16	5	.48	0

The variation of the angle with the relative forebody length is approximately linear. This fact simply means that the center of gravity location is a function of the distribution of displacement rather than of the actual step location. There is no assurance, however, that the performance of the models listed could not be improved by relocating the step to give some reasonably constant relation between the center of gravity and the step. This point is one that should be covered in a general test, preferably as a preliminary investigation, so that the general test is confined to the best step location for the lines in question. The general test data should certainly include curves of static trim, hump trim, and planing trim angles as a function of the fore-and-aft location of the center of gravity and an effort should be made to define the safe limits.

The vertical location of the center of gravity is of less concern than the horizontal location. There is some evidence indicating that the present average height of the center of gravity above the keel line of about 80 per cent of the beam will be maintained. For a single-float type seaplane the average height of the center of gravity above the keel line is about 160 percent of the beam.

CALCULATION OF WATER RESISTANCE

A complete method of calculating take-off resistance and best wing setting is given in reference 3. This method is entirely satisfactory if free-to-trim data are used up to the speed at which sufficient control is available to attain best trim. This speed varies with the type of hull and the load coefficient. It also varies with the characteristics of the flying boat such as center of gravity location, height of thrust line, and amount of control available. One reasonable solution is to fair in connecting links between the free-to-trim curves at the hump and the fixed-trim curves at a speed about 25 percent greater. A suitable alternative is to use free-to-trim data up to a speed 20 percent greater than the hump speed and best trim data from this point to the get-away.

During take-off the wings are close to the water in terms of the span, and it is necessary to make allowance for the increased effective aspect ratio. The increase in lift and reduction in drag at a given angle of attack have an appreciable effect on best wing setting and on take-off.

STICKING

"Sticking" is a term used to designate a rapid increase in resistance just prior to take-off with either increase in speed free to trim or increase in a fixed-angle trim. When the sticking characteristic is pronounced, it may limit possible take-off to a low angle-of-attack fly-off or it may entirely prevent take-off. The trouble is often due to suction near the stern when large curved or chineless areas make contact with the sides or bottom of the trough created by the step. This characteristic is essentially a high speed, light-load phenomenon that should be investigated as a part of the routine preliminary work leading up to a general test. In other words, a set of lines should not be given a complete test until sticking is eliminated or found absent within the useful range in C_Δ.

THE COMPARISON OF HULL LINES

A complete comparison of hull lines requires consideration of many factors: hump resistance, planing resistance, air resistance, moments, spray characteristics, etc. This discussion will be concerned only with the water resistance.

It is important to note that the usual comparison of hull performance in the form of curves of Δ/R against C_Δ using C_V as the parameter may be misleading. The basic design condition is normally a limiting minimum Δ/R at the hump. This characteristic determines the beam of the hull just as a specified stalling speed determines the area required with a given wing section. Comparisons of hulls on the basis of Δ/R at the same speed coefficient is exactly analogous to comparison of wing characteristics at the same lift coefficient. The differences sought are obtained by comparison at the same speed, or at the same percentage of get-away speed, and not at the same value of C_V (unless the beams happen to be the same).

Experience indicates that a comparison of Δ/R curves plotted against V/V_G is a simple and very effective means of evaluating the merits of hull lines. This method requires that free-to-trim data be used through the hump and that best-trim data be used from the hump to get-away. Such curves can be obtained from the usual presentation of general test data but the effort and time required are greater than most engineers are willing or able to expend. It is highly desirable that all reports contain data of this type for use in preliminary design studies. One of the difficulties encountered in any attempt to include this data is the necessity for adopting some particular condition to be represented. If a true comparison is desired, it is not satisfactory to adopt standard values of C_{Δ_0} and C_{V_G}. A standard method should allow for the adoption of the best beam to meet a given set of conditions. One very simple solution would be to adopt a standard weight and

standard get-away speed and then to determine the value of C_{Δ_0} and C_{V_G} required to give a standard minimum value of free-to-trim Δ/R at the hump. The minimum value of $\Delta/R=4.5$ used in reference 3 is as good as any. In order to simplify the calculations the standard value of Δ_0 might be taken as 1,000 w so that

$$\text{Standard } b=10\sqrt[3]{\frac{1}{C_{\Delta_0}}} \tag{8}$$

Likewise the standard value of V_g might be taken as $20\sqrt{g}$ so that

$$\text{Standard } C_{V_G}=\frac{20}{\sqrt{b}} \tag{9}$$

If these, or some similar standard values, are adopted all reports on general tests could include comparative curves of Δ/R against V/V_G.

RANGE OF TESTS

It is exceedingly annoying to find that the range of a test has been insufficient to cover new design conditions. The determination of test limits to avoid this defect is not simple, but it is possible to make certain approximations that serve as a guide.

The conditions at hump speeds are highly important from the standpoint of the designer. Many of the general tests have not covered sufficient range in load coefficient and trim angle at the hump. The tests should be carried far enough to construct complete diagrams of the types shown in figure 2 and figure 4. These diagrams are probably incomplete unless they extend to the load coefficient giving $\Delta/R=4.0$ at best trim.

The range to be covered by the tests will depend to an appreciable extent on the anticipated variation in C_{Δ_0} and C_{V_G} with gross weight. The variation of C_{Δ_0} with gross weight appears to be determined by simple requirements. Physically, C_Δ is the ratio of the weight carried to the weight of a cube of water having b as the length of one side. For a geometrically similar series of flying boats Δ will vary as b^3, and hence C_Δ will remain constant. If the weight increases more rapidly than b^3, then C_Δ and the relative draft must increase; but this increase would mean an increase in hump resistance and an increase in maximum trim angle. In a normal design C_{Δ_0} is determined by the restrictions imposed on hump resistance and maximum trim. These restrictions tend to be more severe as the size is increased. Unless a pronounced favorable scale effect is obtained, the value of C_{Δ_0} required for a given value of Δ/R at the hump is independent of the size of the airplane. It therefore appears unlikely that the values of C_{Δ_0} can be increased as the size of the airplane is increased—unless such increase is obtained by basic improvement in hull lines. In other words, for a given set of lines the range in loading is determined by the limiting conditions at the hump.

The range in speeds to be covered by a general test depends on the extreme values of C_{V_G}, the value of C_V at get-away speed. Since $C_{V_G}=V_G/\sqrt{gb}$, the answer must be found in the variation of V_G with Δ.

It is a generally accepted design axiom that the wing loading must be increased as the design load is increased. The nature and extent of this increase may have an appreciable effect on the range to be covered in hull model tests. It is therefore desirable to investigate the relation between wing loading and gross weight.

If a design series is made geometrically similar in every detail, the gross weight will vary as the cube and the wing area will vary as the square of any given linear dimension. Hence, $W\alpha S^{3/2}$ and $S\alpha W^{2/3}$ or

$$\frac{W}{S}\alpha W^{1/3} \tag{10}$$

This increase in wing loading is sometimes referred to as the "law of the squares and cubes" since it is related to the problems involving the ratio of surface area to volume.

If equation (10) could not be avoided, it would serve as a definite restriction on the size of airplane that could be built and flown. Actually, an exact geometrical similarity in the assumed hypothetical series is not likely to be attained. As the size of the airplane is increased, it is possible to use more efficient structures and more efficient materials with an appreciable saving in structural weight. The general form of equation (10) would therefore be

$$\frac{W}{S}\propto W^{n} \tag{11}$$

and the exponent should be less than one-third.

Reference 24 contains a chapter entitled "Notes on Giant Aeroplanes," prepared by José Weiss and Alexander Keith in 1916. In this chapter it is claimed that the observations of José Weiss on insect flight, bird flight, and gliding experiments show that for satisfactory performance the gross load must vary as the 4/3 power of the wing area. The relation given by Weiss is

$$P=8.5S^{1.33} \tag{12}$$

where P is in kilograms and S is in square meters. Weiss states on pages 152-153 of reference 24 that the load can be increased well above that represented by equation (12) if sufficient power is available but that the natural gliding characteristics may be adversely affected.

Equation (12) is equivalent to

$$\frac{W}{S}\propto W^{1/4} \tag{13}$$

Design practice in the past has shown a marked tendency to approximate the Weiss equation, although there is naturally an appreciable spread due to differences in construction and purpose of the airplanes considered. It is interesting to compare the wing

loadings corresponding to equations (10) and (13) as follows:

Gross weight, W	Equation (10) $\frac{W}{S} \propto W^{1/3}$	Equation (13) $\frac{W}{S} \propto W^{1/4}$
1,000	10	10
8,000	20	16.8
27,000	30	22.8
64,000	40	28.3
125,000	50	33.4
216,000	60	38.3
343,000	70	43.0
512,000	80	47.6

The initial value of 10 pounds per square foot was selected arbitrarily to facilitate comparison but it approximates an average value. Equation (13) appears to give a reasonable variation in wing loading, while equation (10) certainly demands too great an increase in large sizes.

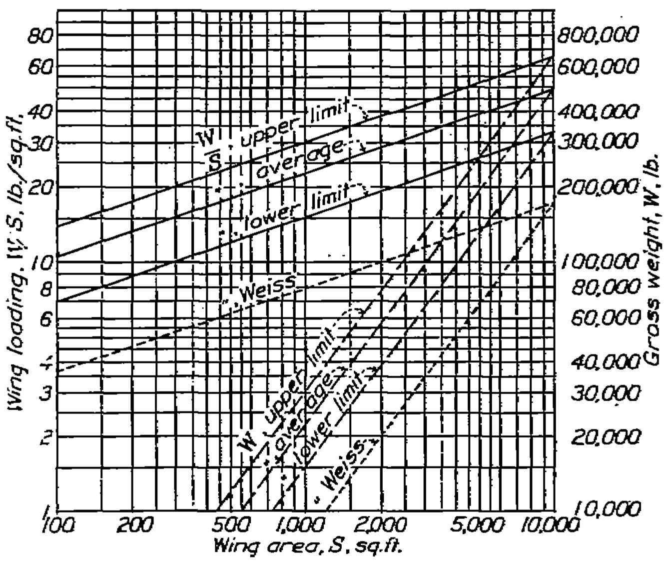

FIGURE 5.—Variation of wing loading with gross weight.

Figure 5 contains a plot of wing loading and gross weight against wing area, based on a tabulation of normal designs. Values from the original Weiss equation are also given. It should be emphasized that the upper limit and lower limit indicated on figure 5 are simply arbitrary values obtained from a tabulation representing normal designs.

Since the value of V_G may be taken directly proportional to the wing loading or, from equation (13),

$$V_G \propto \left(\frac{W}{S}\right)^{1/2} \propto W^{1/8} \tag{14}$$

With constant C_Δ, the beam varies as the cube root of the weight. Hence

$$C_{V_G} \propto \frac{V_G}{b^{1/2}} \propto \frac{W^{1/8}}{W^{1/6}} \propto W^{-1/24} \tag{15}$$

This equation indicates a very slow decrease in the value of C_{V_G} as the weight is increased. A hundredfold increase in W would reduce C_{V_G} less than 18 percent. It therefore appears unnecessary to make any special provision for testing at extreme speeds insofar as the effect of future increase in size is concerned.

CONCLUSIONS

The main conclusions indicated by this study are:

1. The complete general test should not be made on a set of lines until preliminary tests have shown no objectionable characteristics.

2. A standard weight and a standard get-away speed should be adopted to facilitate comparison of lines. The adoption of a standard minimum value of Δ/R free-to-trim at hump speed is also desirable.

3. The value of general hull test data can be greatly increased for design purposes by the inclusion of the following additional data:

(a) A plot of C_Δ against C_V^2 with Δ/R as the parameter using free-to-trim up to a speed about 25 percent above hump speed and best trim data at all higher speeds. (See fig. 3.)

(b) A curve of C_Δ at hump against C_V^2 with Δ/R divisions or graduations along the curve (as in fig. 4).

(c) Curve of maximum trim at the hump as a function of C_Δ for the free-to-trim condition. The form used in figure 2 has some advantages.

(d) Vector diagram at hump speed for a series of values of C_Δ using best trim data.

(e) A vector diagram for a series of values of C_v in a constant lift coefficient take-off for a standard weight and get-away speed.

(f) Curves of static angle of trim as a function of C_{Δ_0} and $c.\ g.$ location. Such curves can be constructed from the static data now supplied, but both forms of presentation are desirable.

4. The range of loads and speeds necessary to supply data for a normal size flying boat appear to be ample to cover future increases in size.

5. There appears to be need for investigation of the following:

(a) Fore-and-aft location of step and best location of $c.\ g.$ relative to step.

(b) Best initial trim.

(c) Effect of thrust moment and elevator moment on trim angles. This will probably require measurement of pitching moments in the full-scale wind tunnel.

BUREAU OF AERONAUTICS,
NAVY DEPARTMENT,
WASHINGTON, D. C., *November 1937.*

REFERENCES

1. Truscott, Starr: The N. A. C. A. Tank—A High-Speed Towing Basin for Testing Models of Seaplane Floats. T. R. No. 470, N. A. C. A., 1933.
2. Parkinson, John B., and Dawson, John R.: Tank Tests of N. A. C. A. Model 40 Series of Hulls for Small Flying Boats and Amphibians. T. R. No. 543, N. A. C. A., 1936.
3. Shoemaker, James M., and Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull—N. A. C. A. Model No. 11. T. N. No. 464, N. A. C. A., 1933.
4. Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull—N. A. C. A. Model No. 11-A. T. N. No. 470, N. A. C. A., 1933.
5. Shoemaker, James M.: A Complete Tank Test of a Model of a Flying-Boat Hull—N. A. C. A. Model 16. T. N. No. 471, N. A. C. A., 1933.
6. Shoemaker, James M.: A Complete Tank Test of a Flying-Boat Hull with a Pointed Step—N. A. C. A. Model No. 22. T. N. No. 488, N. A. C. A., 1934.
7. Shoemaker, James M., and Parkinson, John B.: Tank Tests of a Family of Flying-Boats Hulls. T. N. No. 491, N. A. C. A., 1934.
8. Shoemaker, James M., and Bell, Joe W.: Complete Tank Tests of Two Flying-Boat Hulls with Pointed Steps—N. A. C. A. Models 22-A and 35. T. N. No. 504, N. A. C. A., 1934.
9. Dawson, John R.: A Complete Tank Test of the Hull of the Sikorsky S-40 Flying Boat—American Clipper Class. T. N. No. 512, N. A. C. A., 1934.
10. Parkinson, J. B.: Tank Tests of Model 11-G Flying-Boat Hull. T. N. No. 531, N. A. C. A., 1935.
11. Bell, Joe W.: The Effect of Depth of Step on the Water Performance of a Flying-Boat Hull—N. A. C. A. Model 11-C. T. N. No. 535, N. A. C. A., 1935.
12. Dawson, John R.: A General Tank Test of N. A. C. A. Model 11-C Flying-Boat Hull, Including the Effect of Changing the Plan Form of the Step. T. N. No. 538, N. A. C. A., 1935.
13. Allison, John M.: The Effect of the Angle of Afterbody Keel on the Water Performance of a Flying-Boat Hull Model. T. N. No. 541, N. A. C. A., 1935.
14. Parkinson, J. B.: Tank Tests of a Model of a Flying-Boat Hull Having a Longitudinally Concave Planing Bottom. T. N. No. 545, N. A. C. A., 1935.
15. Dawson, John R.: Tank Tests of Three Models of Flying-Boat Hulls of the Pointed-Step Type with Different Angles of Dead Rise—N. A. C. A. Model 35 Series. T. N. No. 551, N. A. C. A., 1936.
16. Parkinson, J. B.: Tank Tests of Models of Floats for Single-Float Seaplanes—First Series. T. N. No. 563, N. A. C. A. 1936.
17. Bell, Joe W.: Tank Tests of a Model of the NC Flying-Boat Hull—N. A. C. A. Model No. 44. T. N. No. 566, N. A. C. A., 1936.
18. Allison, John M., and Ward, Kenneth E.: Tank Tests of Models of Flying-Boat Hulls Having Longitudinal Steps. T. N. No. 574, N. A. C. A., 1936.
19. Allison, John M.: Tank Tests of a Model of the Hull of the Navy PB-1 Flying Boat—N. A. C. A. Model 52. T. N. No. 576, N. A. C. A., 1936.
20. Dawson, John R., and Truscott, Starr: A General Tank Test of a Model of the Hull of the British Singapore IIC Flying Boat. T. N. No. 580, N. A. C. A., 1936.
21. Ward, Kenneth E.: Hydrodynamic Tests in the N. A. C. A. Tank of a Model of the Hull of the Short Calcutta Flying Boat. T. N. No. 590, N. A. C. A., 1937.
22. Seewald, Friedrich: On Floats and Float Tests. T. M. No. 639, N. A. C. A., 1931.
23. Schröder, P.: Towing Tests of Models as an Aid in the Design of Seaplanes. T. M. No. 676, N. A. C. A., 1932.
24. Weiss, J. Bernard: Gliding and Soaring Flight, A Survey of Man's Endeavour to Fly by Natural Methods. Sampson Low, Marston & Co., Ltd., London.